

# CEMENT AND LIME MANUFACTURE

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## Design and Operation of Modern Lime Works.—XI.\*

By N. V. S. KNIBBS, D.Sc.

### THE OPERATION OF LIME KILNS.

THE operation of lime kilns is an inexhaustible subject owing to the variety of the kilns in use, and it is necessary to limit consideration here mainly to modern types of kiln which are more amenable to systematic treatment. The behaviour of the older short types of kiln depends largely on atmospheric conditions, wind, and the contour of the surrounding country, and their successful operation depends as much on skill in forecasting the weather and adjusting the draught, etc., to meet changes in wind and weather as on knowledge of the conditions necessary to burn good lime. In other words, long local experience is of more value than the most extensive scientific knowledge when operating such kilns. In modern types of kiln skill in design replaces skill in operation.

### Stone Size and Grading.

The effect of the size of limestone on the time required for its calcination has already been discussed<sup>1</sup>, and it has been shown that the time increases rapidly with increase of size. From the point of view of calcination, therefore, the smallest stone is the best, but apart from the limitation placed upon size by the design of the plant there are two factors to be considered. One is the cost of reducing stone to small size and the other is the necessity, at present, of producing lime in the form of large lumps, to meet the market demand.

Stone for vertical shaft kilns of the designs at present used must be in lumps of 4 in. upwards, and generally speaking 6-in. lumps are preferred. The ideal would be to have exactly evenly graded stone of the required size, because in

\* Previous articles in this series appeared in our issues for January, February, March, April, May, August, September, October, November and December, 1937, and January, 1938.

<sup>1</sup> "Cement and Lime Manufacture," Feb., 1937, p. 49 *et seq.*

the ideal kiln with a uniform burning temperature such stone would be evenly burnt. In quarries where there is a sale of limestone far in excess of the amount of stone used for lime burning it would be feasible to pick out an evenly-graded stone of this kind. In other quarries it would be possible to pick out a number of even grades of stone, or to separate the whole quarry output into grades mechanically, and to burn these different grades in kilns designed for the purpose. Unfortunately there are few lime plants with an output large enough to justify either procedure, and ordinarily it is necessary to calcine in one kiln a fairly wide range of stone sizes so as to avoid wasting any large quantity of quarried stone. Nevertheless, the quality of lime and the output and efficiency of the kilns of nearly all existing plants could be improved by closer attention to using more evenly graded stone.

Stone for static kilns, especially ring kilns, may be larger than for shaft kilns because the time of burning is generally much longer. This is an advantage only when there is a demand for large lumps—a demand which is dying out. Chalk for shaft kilns may be, and generally is, larger than limestone because it breaks up much more in the kiln, especially in the upper zone where it dries out.

Rotary kilns are fed with stone which is generally between  $\frac{1}{2}$  in. and  $1\frac{1}{2}$  in., but stone up to 3 in. has been burnt in them. In rotaries it is even more important than in vertical kilns to have an even grading, and the best size is probably about  $\frac{3}{4}$  in., but much smaller stone of even grading may be used without difficulty. Trouble arises when small stone is mixed with larger stone. Close grading would greatly improve the efficiency of these kilns.

#### Cleanliness of Stone.

Limestone in mass is often of very high purity, and if it could be quarried without any adhering soil and without the impurities that occur in crevices, etc., the lime produced from it would be of higher purity than it generally is. The difference between the analysis of a picked sample of limestone and an average sample of the lime produced from it is notoriously wide. It is due not only to impurities introduced in burning but also to impurities in crevices or from clay "backs," and to surface soil coming from the overburden. By hydraulic stripping of the overburden and washing out the crevices the loose impurities may be entirely removed, but hydraulic stripping is seldom economically possible and it is practised in comparatively few limestone quarries. In quarrying, much of the soil may be avoided by keeping a clean floor, but in winter with all precautions possible short of hydraulic sluicing it may be impossible to avoid some surface soil, and washing the kiln stone is seldom practised. Where water is available, however, and where the limestone is of high purity, it may with advantage be adopted. A jig washer may be employed. Where there is much clay it is not possible fully to mechanise quarry operations unless washing is undertaken, and as a sufficient water supply is seldom available dirty quarries are perforce largely worked by manual methods.

In the lime kiln, masses of clay generally flux with the lime and are drawn as solidified slag. Smaller quantities and thin surface coatings generally adhere

to the lime and must be separated by sorting if a pure product is desired. Small quantities of clay-like impurities are often a source of unsoundness in the lime putty or hydrate produced, because a thin coating renders only a very thin skin of the lime unsound and this may break up to fine particles which pass the sieve or other device used to separate the coarse material.

### Charging.

The various devices available for charging lime kilns have already been discussed<sup>2</sup>. The ideal kiln would be charged at a rate corresponding to the rate at which heat is generated, so that a kiln in which the draught is reduced at night would be charged rapidly during the day and slowly at night. This would not be convenient, and generally speaking kilns are either charged and discharged throughout the 24 hours or they are charged during the day shift only. The design shown in Figs. 7 to 10<sup>3</sup> enables a kiln to be charged during the day and yet to retain all the advantages of a kiln charged evenly night and day, but the provision of a storage zone at the top is generally applied only to gas-fired kilns. It is not generally applicable to mixed-feed kilns because it is not practicable to allow the fuel to fall such a height when beginning charging in the morning; it would be crushed by the stones falling on it, and also it would be impossible to make sure that its distribution was correct. Mixed-feed kilns that are discharged throughout the 24 hours are therefore charged throughout the 24 hours. The majority of mixed-feed kilns producing lime for general purposes, however, are charged and discharged by day only. At night the burning zone rises in the kiln and the preheating zone progressively shortens so that sometimes these kilns show red at the top. They should be made long enough to avoid this, as the higher burning zone is accompanied by considerable loss of thermal efficiency.

The charging of limestone to a gas-fired kiln simply consists in its introduction into the shaft by the most expeditious method without damage to the lining, and this also applies to those mixed-feed kilns in which all the fuel is introduced at a point or points some distance from the top.

The charging of a mixed-feed kiln of the simple type is bound up with the introduction of the fuel, and this is discussed later under "Mixed-feed Firing."

A rotary kiln for burning limestone is charged from a storage hopper by a mechanical feeding device. A rotary table-feeder is the usual form adopted, and this is infinitely variable by adjustment of the plough and by variation of speed. In a shaft kiln the rate of discharge controls the rate of charging and of passage through the kiln, whilst in a rotary the rate of charge controls the rate of passage and the discharge.

### Drawing.

As with charging, the ideal method of drawing a kiln that is operating continuously is to draw it continuously at a rate corresponding to the rate of burning. Continuous discharging is employed to a limited extent in shaft kilns, the methods

<sup>2</sup> "Cement and Lime Manufacture," March, 1937, p. 76 *et seq.*

<sup>3</sup> *Ibid.*, pp. 74 to 77.

adopted having been discussed previously,<sup>4</sup> but the majority are still discharged at intervals. Continuous discharge has been tried in some kilns and discontinued, because it caused uneven flow down the shaft; one side of the shaft becomes slightly hotter than the other, the lime on that side adheres more to the lining and the slight movement of slow discharge is not enough to cause it to fall off, so that the lime moves down on one side only. When a large quantity is discharged at once a cavity is formed instantaneously over the whole area and any slightly-adhering lime is subjected to a considerable force tending to loosen it. Kilns that are not provided with continuous discharge should be drawn as frequently as possible consistent with drawing each time sufficient to create such a cavity and thereby facilitate even flow down the shaft. Ordinarily it is found that drawing every 45 or 60 minutes will do this in a kiln operating at high capacity, and about every two hours in a kiln operating at medium capacity.

From a rotary kiln the lime is automatically discharged at a rate corresponding to that of the stone feed, but the depth of stone and lime in the kiln depends on three factors—the rate of feed, the slope of the kiln, and the speed of rotation. It also depends to a minor extent on the shape of the pieces of stone. The time of passage through the kiln is directly proportional to the load, and therefore a kiln burning large stone should be heavily loaded. In practice the depth in the kiln is limited because of the lack of penetration of the heat through a deep charge, and the best load is found by experience. The more even the stone grading the greater may be the depth of material in the kiln.

### Sticking.

Vertical shaft kilns sometimes fail to "follow down" when lime is drawn. They are then said to "stick" or "arch." Sticking seldom occurs in most mixed-feed kilns, more often in gas-fired kilns, and very frequently in furnace-fired kilns, which, indeed, are generally operated so that they stick after each draw and have to be poked down by hand. This procedure results in more even burning than when they follow down at each draw.

In normal operation, unless a kiln is very badly designed, it sticks only at the zone of highest temperature, but on starting up the kiln it is not unusual for it to stick in the stone preheating zone if the kiln is of small diameter or if there is a constriction in that zone. On starting up, kilns are generally filled to the top with stone and, filled in this way without simultaneous withdrawal at the bottom, a kiln will hold much more stone than when in normal working because it lies together more closely. In operation the material is constantly being withdrawn from the bottom and this loosens it all the way up to a point close to the top. As a consequence of its denser packing it may arch sufficiently near the top, especially with the aid of a little adhering clay, to require poking down. When a kiln is drawn regularly it should never arch at this position.

Sticking in the burning zone is primarily due to temperature, but there are several contributory factors. Clay adhering to the stone fluxes at a compara-

<sup>4</sup> "Cement and Lime Manufacture," March, 1937, p. 82, *et. seq.*

tively low temperature and causes the lime to stick together and to the refractory lining. An unsuitable lining will flux with the lime and cause adherence of the latter, but such a lining would have a very short life and consequently this is seldom an important factor. Unevenness in the lining, especially in small kilns, is a frequent cause of sticking, and linings that have been in use for a considerable time and which have worn or fluxed away unevenly often cause sticking. Impure limestones tend to sinter together and to the lining at relatively low temperatures but, because anything approaching a sintering temperature will completely spoil the lime, sticking is seldom due to this cause. Soft stones, and especially wet chalk, stick together by compression and remain adhering when burnt to lime. A uniformly graded stone is much less liable to stick than one of greatly varying grade, and the more suitable the grade from the point of view of calcination the less will be the tendency to stick.

#### Mixed-Feed Firing.

The firing of mixed-feed kilns of the simple form consists merely in the correct distribution of the right amount of fuel amongst the limestone. In large open-top kilns with mechanical charging a layer of stone is dumped on to the top of the stone already charged in quantities depending on the size of the skip or bucket used for charging. Having placed a layer of limestone, the fuel is charged in the same way but in smaller amounts, and generally it is necessary to do some hand spreading to obtain even distribution. Smaller open-top kilns are generally fired by hand, the stone being dumped on a platform at the top of the kiln or in the kiln and then spread by hand, and the fuel is spread over the stone by shovelling. In closed-top kilns the distribution is done mechanically<sup>5</sup> and it is necessary only to fill the correct amount of stone and fuel into the charging hopper above the kiln. In both types of kiln excessive draught up the wall may be avoided by segregating small stone there, either by hand or by mechanical selection<sup>6</sup>, and it is best to avoid distributing fuel against the walls. If the stone and fuel are charged correctly, control of the kiln then depends on regulation of the draught, which is dealt with later.

Mixed-feed kilns in which the fuel is charged separately and lower down the shaft are divided into those in which it is simply emptied down a chute into the kiln as in *Fig. 19A*<sup>7</sup>, and those in which the shaft is arched across leaving a space into which the fuel is thrown and spread by hand. In the former there are several charging chutes and the fuel is uniformly distributed between them at intervals corresponding to the discharging times. In the latter the fuel is spread over the available area at frequent intervals, so as to make the best use of the volatile matter evolved. These kilns are generally charged and drawn by day only and firing is also done by day, the draught being regulated as described later.

<sup>5</sup> "Cement and Lime Manufacture," March, 1937, p. 78.

<sup>6</sup> *Ibid.*, Fig. 11, p. 78.

<sup>7</sup> *Ibid.*, August, 1937, p. 215.

### Gas Firing.

Gas firing of modern kilns with clean gas of uniform quality supplied from an outside source, whether it is natural gas, coke-oven gas, blast-furnace gas, or a mixture, is a simple operation. Once the gas supply between the different ports is adjusted correctly the valves may be left untouched for months at a time. On the other hand, a kiln fired by gas made in attached or adjoining producers is subject to variation in the operation of the producers and generally also to the discontinuity caused by the necessity of periodically burning out the soot deposited in the flues. Gas made in producers operated by hand is liable to variation due to difference in the skill of those in charge. If the producers are not fed at regular frequent intervals the composition of the gas changes suddenly, and the same thing may happen if the fuel bed is not kept free and even by sufficient poking. The amount of attention required to produce gas of even quality varies greatly with different fuels and with the size of the fuel, and it is common on plants using small coal or a poor quality nut coal to find a great decrease of kiln efficiency at night when there is least supervision. The quality of the gas alternates between very rich after a large charge of coal is put on to a hot fire, and very poor after a spell without coal and without poking. Consequently, at one time there is insufficient air in the kiln to burn the rich gas and heat is lost as smoke, and at another time there is a large excess of air with consequent low efficiency. Mechanical charging of coal to the producer prevents uneven charging, but it is not a complete cure for lack of skill or care in attending the producer. The fully mechanical gas producer, which is fed, stirred, and discharged mechanically, produces gas of even quality and is particularly desirable when poor quality or high-ash coal is to be gasified.

Given an even quality of gas from a mechanical or from a hand-operated producer, the kiln attendant, having once set the valves, has only to see that they do not become choked with soot and that the gas flues and outlets remain sufficiently clear. Any constriction, such as may occur at a valve, will first tend to choke with soot and, as this seldom happens evenly at all valves, the relative flow of gas to the different valves is altered. It is therefore necessary to clear any constricted valves at sufficiently frequent intervals, which depend on the temperature and cleanliness of the gas and also on the design of the gas valve. A kiln is best designed to operate with the valves fully opened so that in effect there is practically no constriction there, and the valves are used only for the purpose of closing off the gas entirely, but this is not always possible. Soot is also deposited in the flues and at the ports leading into the kiln, which must be cleared at intervals. On many kilns it is a practice to burn out completely once a week the flues leading from the producer to the kiln, and to burn out the ports leading into the kiln every shift. The former is accomplished by closing the valve at the outlet of the producer and admitting air at an adjacent explosion door, when the soot ignites and burns under the natural draught of the kiln. Ports into the kiln are burnt out by shutting the valve controlling each port and admitting air at an access or explosion door.

The amount of gas supplied by the producer is controlled primarily by the volume of air blown into it, and the quality of the gas is controlled by the amount of coal charged and the amount of steam or other endothermic agent employed. To make good gas a relation must be maintained between the volume of air and the coal charged, that is to say they must vary together, so that when the output of the kiln is increased, and therefore the rate of coal feed correspondingly increased, a similar change is made in the air blown in.

The steam required for mixing with the air depends upon the quality of the coal. Generally speaking, an amount corresponding to a saturation temperature between 45 and 60 deg. C. is needed, and high-quality coal may be successfully de-gasified at saturation temperatures close to the lower of these figures, which gives a better quality gas and one better suited to lime burning than a high saturation temperature. When the air for the producers is blown in by a steam injector there is always more than sufficient steam in the air, and control of the saturation is practically impossible. Producers so operated work satisfactorily but are not as efficient or as easily controlled as those in which the air is supplied by a fan.

When exhaust gases containing carbon dioxide are used instead of steam the proportion may be assessed either by the appearance of the gas producer or by a CO<sub>2</sub> indicator or recorder. The amount that will prevent overheating depends as before on the quality of the coal, but a mixture with between 3 per cent. and 5 per cent. CO<sub>2</sub> is usually sufficient.

There is a good deal of misconception about the supposed necessity of delivering gas to the kiln at pressure in order that it may force its way amongst the lime and spread across the shaft. This is entirely wrong. The gas pressure, in itself, has no bearing on the spread of the gas across the kiln. Velocity at the point of entry (i.e. at the gas port) has some effect on the penetration of the gas<sup>8</sup>, and this velocity is higher the smaller the area of the gas port. Since a small port offers greater resistance than a large one, the pressure drop at the port will be greater when it is small, and consequently the required gas pressure will be slightly higher. However, the size of the gas port is fixed and the aim in operating the kiln should be to work with as low a gas pressure as possible consistent with getting the required volume into the kiln. The common misconception as to the supposed effect of gas pressure has led to such absurdities as the partial closure of the gas valves until a pressure develops in the gas main, with the idea that this will improve gas penetration.

The volume of gas entering the kiln at a port in relation to the total draught in the kiln shaft influences the distance across the shaft the gas flame travels, and the greater the volume the farther the distance of penetration. For this reason kilns with side ports only must not have too many of them. The distribution of the gas between a large number of side ports leads to bad penetration and underburning in the centre of the kiln. To improve the penetration some kilns are operated with only half their gas ports in use at any one time,

<sup>8</sup> See "Cement and Lime Manufacture," Sept., 1937, p. 248.

the gas supply being alternated between the two sets of burners. The device is useful in overcoming the deficiency of kilns whose design does not ensure proper distribution, but it is necessarily less efficient than a properly designed kiln with a continuous supply of gas to all ports.

#### **Rotary Kiln Firing.**

The firing of a rotary kiln with coal dust or oil is similar to that of a cement kiln, except that the temperatures are lower. The clinker coating that forms on, and protects, the lining of a cement kiln is not present in a lime kiln, and to obtain a satisfactory life of the lining it is necessary to operate at temperatures below those at which there is active fluxing with the lining. Furthermore, when firing with coal dust, too high a temperature causes fluxing of the coal ash on the surface of the lime, which is then of less value. It may also cause the formation of rings on the kiln lining similar to the clinker rings of cement kilns.

Gas firing of a rotary kiln offers the same problem as the gas firing of a vertical kiln, but as there is generally only one kiln supplied from one producer (which is often a mechanical one) the flues are simple and short and valves may be dispensed with or limited to one at the producer outlet. Interruption for burning out the flues should be unnecessary on rotary kilns.

#### **Static-Kiln Firing.**

Most ring or other static kilns are fired with coal in contact with the lime, and their firing is attended to by operatives whose long experience has taught them how to work the plant. Nevertheless, static kilns are particularly well suited to precise control because it is easy to measure the temperature in them and to obtain gas samples for analysis at any desired point. The use of temperature measurements and gas analysis in control is discussed later.

#### **Regulation of Draught.**

Having charged the fuel in the mixed-feed kiln, or having set the valves in an oil-fired or gas-fired kiln, and having also set the rate of discharge, the remaining variable that may be controlled is the draught. On a mixed-feed kiln the draught, that is to say the quantity of air per minute drawn into the kiln, controls the rate of burning and therefore of heat generation. On a gas-fired kiln, on the other hand, the rate at which the fuel is supplied and burnt is independent of the draught, except that if there is insufficient draught combustion is incomplete. These facts are the basis of the essential difference in control of the two types of kiln. If a mixed-feed kiln is operated with too much draught the temperature will rise too high and carbon monoxide will be formed. A gas-fired kiln, on the other hand, may be operated at any desired rate provided the gas supply is adjusted to the draught; in fact, it is easier to secure complete combustion in a kiln operated at high than at low capacity. In operating a mixed-feed kiln, therefore, the draught is regulated so as to conform to the amount of lime drawn. Too little draught will result in a hot lime being discharged,

whilst too much will raise the level of the burning zone in the kiln so high that the exhaust gases become too hot. A change in the draught does not result in excess air in the exhaust or in incomplete combustion except insofar as the conditions lead to the formation of carbon monoxide. Minor variations in draught, due to wind or to operating conditions, do not greatly affect the efficiency of burning. In a gas-fired kiln the draught must conform not only to the amount of lime drawn but also to the amount and quality of the gas supplied. Assuming that the gas remains constant in amount and quality, the draught should remain constant, and any variation will lead to inefficiency through insufficient or excess air for combustion. Moreover, the quality and quantity of gas may, and do, vary, especially with hand-operated producers, thus introducing further scope for inefficiency. It is partly for these reasons that early gas kilns were relatively unsuccessful. Most of them operated on natural draught, and the variations introduced by wind, by cold and wet stone, and other causes made it impossible to maintain the conditions necessary for efficiency. Even in modern gas-fired kilns, where the blowers to the producers and exhausters from the kilns assist greatly in the maintenance of a uniform supply of gas and draught, the variation from optimum conditions is as a rule far greater than it would be if proper attention were given to control of the draught and management of the producer.

On a kiln operating on natural draught the flow of air and gases is regulated at the inlet or at the outlet by dampers or baffles at some point of constriction. If the kiln is open at the top it is impossible to regulate there, so the air inlets must be controlled, but closed-top kilns are best regulated at the outlet because then the kiln is under minimum suction everywhere and indraught of air at undesirable points is reduced to a minimum.

On a kiln with mechanical draught the best method of regulation is by changing the speed of the fan, but since this is seldom possible except at prohibitive cost in control gear when the electrical supply is A.C., it is more usual to regulate by damper which should be placed on the outlet side of the fan if it is an exhauster, or on the inlet side of a blower.

On mixed-feed kilns fired with bituminous coal which is charged through the side of the shaft the draught has to be regulated to suit the programme of firing. Ordinarily these kilns are drawn, charged, and fired during the day only, but they continue to burn through the night. Some of the air for combustion enters at the bottom and some is drawn in at, or just below, where the coal is charged, so as to be available for burning the volatile combustibles. Whilst charging coal it is necessary to admit enough air at this higher zone to burn all the volatile matter, but at night, after ceasing to charge coal, this supply of air is no longer necessary. The air entering at the bottom during the day should be limited. It must not be enough to burn all the non-volatile matter in the coal, otherwise the level of the fire in the kiln will remain stationary during the day and will rise too high in the night. During the day's charging and discharging the fire must fall to a low level, whilst at night, when the kiln is not being drawn, it

risers. The efficiency of these kilns depends to a considerable extent on the management of the draught, and particularly its correct distribution.

### Draught Gauges.

All kilns with mechanical draught should be fitted with draught gauges wherever possible. If the pressure or suction is reasonably high, say over 1 in. water-gauge, a simple water-gauge manometer will serve the purpose, but when very low pressures are to be measured it is necessary to have either a special sloping manometer (which by being fixed exactly at a slope of 1 in 10 multiplies the reading 10 times, so that  $\frac{1}{10}$  in. water-gauge is spread over a length of 1 in.) or one of the sensitive forms of gauge in which the pressure is generally indicated on a dial. For kilns operating on forced draught and burning small stone the pressure is sometimes so high that a water manometer would be inconvenient and then a mercury manometer or a Bourdon gauge may be used.

It is necessary to appreciate the limitations of manometric gauges as indicators of the draught in a kiln. If the resistance through the kiln were invariable, and the average temperature remained constant, the suction or pressure at the outlet or inlet would be an accurate guide to the draught. Under practical kiln conditions, however, both the resistance and the temperature vary considerably, and the manometric reading is a function of resistance, temperature, and draught. To measure the actual draught some sort of flow meter is required, and these instruments will be discussed later. Nevertheless, simple draught gauges are exceedingly useful in kiln operation and the majority of kilns are in fact operated without any more exact draught indicators.

(To be continued.)

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## Recent Patents Relating to Cement.

473,834.—Refractories. Magnesital Ges. March 16, 1936.

The resistance of magnesia refractories such as magnesite bricks to spalling is increased by incorporating therein a small proportion, preferably 2 to 6 per cent., of one or more highly refractory substances, other than alumina or aluminous substances, which retard or arrest the formation of periclase crystals when the articles are burnt and providing that in the raw material the proportion of coarse grain (over 0.8 mm.) to medium grain (0.8 to 0.1 mm.) to fine grain (below 0.1 mm.) is approximately 5: 2: 3; however, the content of the coarse grain and the fine grain may vary

by about one-third in either direction, while the content of the medium grain, which should not exceed 25 per cent., may be omitted. Highly refractory substances specified are chromite, chromium oxide, pyrolusite and magnesium silicates such as talc.

473,847.—Cement. Fasting, J. S. April 20, 1936.

In wet process for the manufacture of cement, dust is removed from the kiln gases by causing them to pass through a porous mass which is moistened by slurry of such dilutions that it will acquire normal consistency by taking up dust.

## The Specific Surface of Cement and Ground Rock.

By H. ELSNER VON GRONOW.

IN the course of a paper in *Tonindustrie Zeitung* recently the author points out the inability of sieves to give a correct idea of the fineness of cements and discusses the advantages of stating the fineness of a cement as its specific surface in square centimetres per gram. He notes that in the United States the usual method of measuring surfaces is optically by the Wagner or the Klein turbidimeter, whereas in Germany the sedimentation method is more popular. The paper discusses the results of sedimentation tests and includes a description of a graphical method of obtaining the specific surface of a cement from its grading analysis.

In Fig. 1 (see also Table I) two grading analyses of the same cement are given. The product represented by curve *b* differs from that represented by curve *a* in the time of grinding, and it is therefore finer. These sedimentation tests were carried out at the laboratory of the Verein Deutscher Portland-Cement-

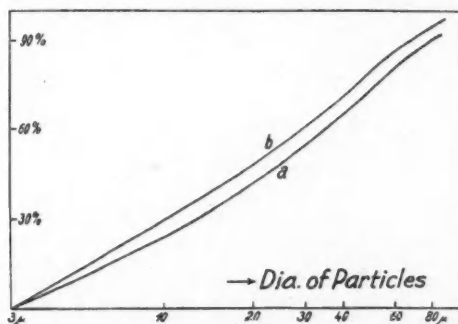


Fig. 1.—Particle size distribution curves of Two Cements.

TABLE I.

Particle size to	10μ	20μ	30μ	40μ	60μ	88μ
Silo cement, not dried .. ..	23.6	41.6	55.4	65.1	80.9	92.2
" " dried .. ..	23.8	41.6	52.2	65.5	81.1	92.4
" " reground .. ..	29.3	48.2	61.2	71.3	87.1	96.4

(The differences between the dried and undried cements are seen to be quite small.)

Fabrikanten at Karlshorst for the author, who is indebted to Dr. Haegermann for the results.

Due to their very small amount the particles less than  $3\mu$  in diameter have been neglected; therefore, the curve which represents the relation between the percentage of a particular particle size and the logarithm of the particle size passes through the point 0 per cent. for  $d = 3\mu$  (Fig. 1). The curves *a* and *b* are not straight lines, but are very slightly S-shaped. Mixtures of mineral particles

with this type of particle size distribution always result from "natural" grinding processes (grinding in a compound mill, crushing in hammer mills, etc.) and may be used to give the greatest possible density in a concrete containing an aggregate consisting of particles of varying diameters.

The surface  $O$  of a mixture of various mineral particles, each size being of percentage  $p$  with a specific gravity  $s$  is, for a cubical shape of the particles,

$$O = \sum \frac{6}{s \cdot d_m} \cdot \frac{p}{100}$$

This surface can be expressed graphically as a quadrant surface

$$O = \frac{r^2 \cdot \pi}{4}$$

From which it follows, for  $s = 2.65$ , that

$$r = \frac{1.7}{\sqrt{d}}$$

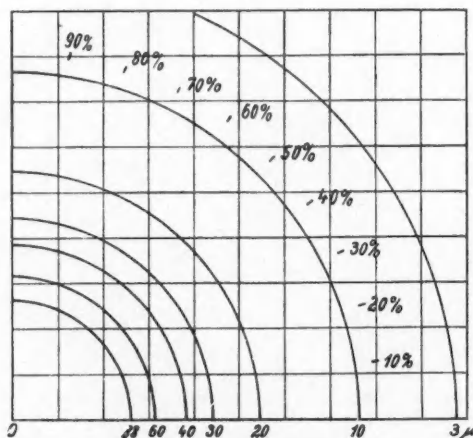


Fig. 2.—Quadrant Diagram for determining the Surface of a Cement.

If graph paper with co-ordinates as shown in Fig. 1 is not obtainable, the above co-ordinates are drawn on a piece of paper to any desired scale, another sheet of paper is then laid on it and the results of the grading analysis are plotted on the upper sheet on which a rectangular co-ordinate system is drawn. In this way the final diagram as shown in Fig. 3 is obtained.

The surface of all the particles contained in one gram of the particle size fraction with  $d_m = 0.35$  mm. is represented accordingly by a quadrant with the radius

$$r = \frac{1.7}{\sqrt{0.035}} = 9.1 \text{ cm.}$$

The other particle fractions are drawn with the same centre ( $o$  in Fig. 2), the radii being obtained in the same way as shown; these radii will be greater according

as the corresponding particle size is smaller. The scale of the diagrams as drawn in *Fig. 2* will be conditioned by the radius for the smallest particle fraction. If a mixture contains 24 per cent. of the finest fraction its surface will be represented by the sector  $O-F-10\mu$  in *Fig. 3* (the quadrant has been divided into 100 parts).<sup>\*</sup> By plotting the larger particles sizes taken from curve *a* (*Fig. 1*) in *Figs. 2* or *3*, the curve in *Fig. 3* is obtained which represents the particle size analysis of the cement in the new way. For instance, it can be seen in *Fig. 1* (curve *a*) that 55 per cent. of the cement has a particle size less than  $30\mu$ , therefore  $\frac{55}{100}$  is plotted on the quadrant in *Fig. 2* which cuts the abscissa at  $30\mu$  and the particle size point  $F'$  in *Fig. 3* is obtained. The curve *a* in *Fig. 1* and that in *Fig. 3* therefore represent the same thing. *Fig. 3*, however, gives directly the physical magnitude in question, i.e., the total surface of the mineral mixture. The surface below the

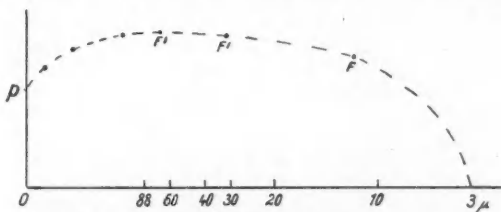


Fig. 3.—Specific Surface of a Cement expressed as the Area of a Curve.

The specific surface of the cement is given by the area  $OPF'F'F3\mu$ . The area is obtained by measurement with a planimeter and multiplied by 100 in order to obtain the true numerical value of the specific surface of the cement if the scale of *Fig. 3* has been reduced in the ratio of 1 : 10 compared with the radii given by equation 3.

curve gives an idea of the magnitude of the surfaces of the particles of the mixture consisting of several different sizes, and also the actual quantity can be obtained by measuring the surface with a planimeter. It should be noted here that if a scale reduced in the ratio 1 :  $k$  is used in the diagram the surface in *Fig. 3* is reduced in the ratio 1 :  $k^2$ . The surfaces of the individual particle fractions are represented by the triangles  $OF'F'$ ,  $OF'F$ , etc.

The author describes the application of this method to aggregates for mixing with bitumen such as is used for roads. In discussing its application to commercial cements he noted that the amount of the particle fraction with diameters 3 to  $5\mu$  is very small and does not contribute much to the strength of a mortar or concrete. For this reason the zero point of the curve is taken as  $3\mu$ , i.e., the amount of particles less than  $3\mu$  is taken as zero. A similar state of affairs exists in the case of bitumen fillers where particles with diameters of the same order as the thickness of the bitumen layer between the particles (about  $4\mu$ ) should be considered part of the bitumen and not of the filler.

<sup>\*</sup> The quadrants have been omitted in *Fig. 3* for clearness, but their intersections with the abscissa are shown.

## The Thermal Efficiency of the Rotary Cement Kiln.\*

By HANS GYGI. (Zurich.)

### III.—THE PROCESSES OF HEATING AND BURNING.

(Continued.)

#### (2) Investigation of the Combustion Process in the Pulverised Coal Flame.

It is possible to obtain a picture of the processes of combustion in the pulverised coal flame by taking samples of the gas and submitting them to complete analysis.\* Although the calorific value of the volume sampled and analysed cannot be determined in this way, it is possible to calculate the quantity of heat that has been liberated in the combustion gases.

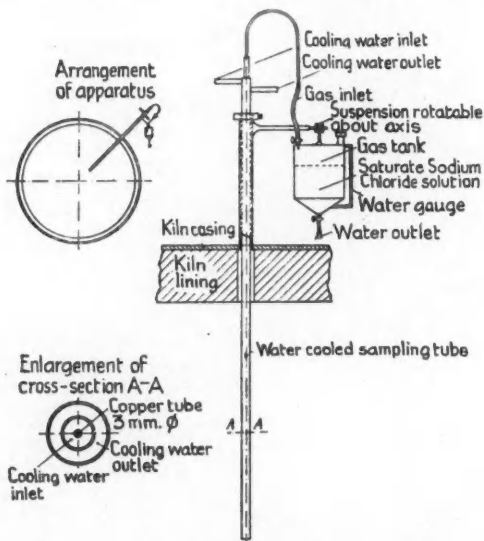


Fig. 16.—Apparatus for taking gas samples from the flame while the kiln is rotating.

The state of combustion can be exactly defined according to Rummel and Schwiedessen<sup>15</sup> by relating the quantity of heat liberated for each unit of volume,  $H'_e$ , to the calorific value,  $H'_m$ , of that quantity of fuel from which 1 Nm<sup>3</sup> dry combustion gas has been evolved in the volume under consideration. The ratio

$$\alpha_m = \frac{H'_e}{H'_m} \quad \dots \quad (2)$$

will be termed the mean combustion ratio.

\* Previous articles in this series appeared in this journal for November and December, 1937, and February, 1938.

TABLE 8.—GAS ANALYSES FOR CROSS-SECTION 10.

	Centre.		20 cm. from centre.	40 cm. from centre.	60 cm. from centre.
Date and time of sampling	14.10.1935 11.00			14.10.1935 16.30	
Chemical composition of the gas.	Sample 1 from pipette 2. (%)	Sample 2 from pipette 4. (%)		Sample 1 from container. (%)	Sample 2 from pipette. (%)
CO <sub>2</sub> ... ..	21.2	21.0		20.6	22.4
C <sub>m</sub> H <sub>n</sub> ... ..	0.2	0.3		0.2	0.2
O <sub>2</sub> ... ..	2.0	2.2		1.4	2.3
CO ... ..	0.8	0.7		0.3	0.4
CH <sub>4</sub> ... ..	0.3	0.3		0.3	0.2
H <sub>2</sub> ... ..	0.9	0.9		0.7	0.9
N <sub>2</sub> ... ..	73.9	74.2		75.8	72.5
Total ... ..	99.3	99.6		99.3	98.9

TABLE 9.—GAS ANALYSES FOR CROSS-SECTION 11.

	Centre.		20 cm. from centre.		40 cm. from centre.		60 cm. from centre.	
Date and time of sampling	15.10.1935 10.00		15.10.1935 13.00		16.10.1935 14.00		17.10.1935 7.30	
Chemical composition of the gas.	Sample 1 from container. (%)	Sample 2 from pipette. (%)	Sample 1 from container. (%)	Sample 2 from container. (%)	Sample 1 from container. (%)	Sample 2 from container. (%)	Sample 1 from container. (%)	Sample 2 from pipette (%)
CO <sub>2</sub> ... ..	14.6	14.2	14.9	14.8	15.6	15.2	12.8	12.8
C <sub>m</sub> H <sub>n</sub> ... ..	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1
O <sub>2</sub> ... ..	2.0	2.8	3.0	2.8	2.9	2.8	4.3	4.5
CO ... ..	0.6	0.6	1.1	1.0	2.0	1.8	0.4	0.6
CH <sub>4</sub> ... ..	0.1	0.1	0.2	0.2	0.3	0.4	0.0	0.2
H <sub>2</sub> ... ..	0.4	0.4	0.0	0.4	0.1	0.1	0.0	0.5
N <sub>2</sub> ... ..	80.6	79.8	80.4	80.2	78.7	79.5	82.1	81.2
Total ... ..	99.3	98.0	99.7	99.6	99.7	99.9	99.7	99.9

TABLE 10.—GAS ANALYSES FOR CROSS-SECTION 12.

	Centre.		20 cm. from centre.		40 cm. from centre.		60 cm. from centre.	
Date and time of sampling	17.10.1935 8.30		17.10.1935 10.00		18.10.1935 8.30		18.10.1935 9.00	
Chemical composition of the gas.	Sample 1 from pipette. (%)	Sample 2 from container. (%)	Sample 1 from container. (%)	Sample 2 from container. (%)	Sample 1 from container. (%)	Sample 2 from pipette. (%)	Sample 1 from container. (%)	Sample 2 from pipette (%)
CO <sub>2</sub> ... ..	12.4	12.4	12.8	12.7	12.8	12.2	10.4	10.3
C <sub>m</sub> H <sub>n</sub> ... ..	0.1	0.1	0.1	0.1	0.2	0.1	0.0	0.0
O <sub>2</sub> ... ..	2.7	2.5	2.7	2.8	3.3	3.7	6.3	6.3
CO ... ..	2.1	2.0	2.0	2.2	2.9	3.1	0.8	0.7
CH <sub>4</sub> ... ..	0.9	0.8	1.0	0.9	0.9	1.0	0.8	0.8
H <sub>2</sub> ... ..	0.4	0.4	0.4	0.3	0.0	0.0	0.0	0.0
N <sub>2</sub> ... ..	81.3	81.5	80.4	80.4	79.2	78.6	80.8	81.0
Total ... ..	99.9	99.7	99.4	99.4	99.3	8.07	99.1	99.1

### Sampling and Analysis of the Gases.

The extraction of samples from the flame was a matter of considerable difficulty, because it was necessary to fit a water-cooled sampling tube to the rotating kiln and to provide a movable container for the sample. The arrangement of the apparatus is shown in *Fig. 16*. The time required to fill the container, which held about 6 litres, was about 4 minutes, i.e. about three revolutions of the kiln. The sample was then analysed. While  $\text{CO}_2$ , the heavy hydrocarbons,  $\text{O}_2$  and  $\text{CO}$  could be determined directly by an absorption method, a combustion method had to be used to determine  $\text{CH}_4$  and  $\text{H}_2$ .

Following the procedure of the Laboratory for Heating Research<sup>16</sup> at Dusseldorf,  $\text{CH}_4$  and  $\text{H}_2$  were ignited together by an incandescent platinum filament and converted to  $\text{CO}_2$  and  $\text{H}_2\text{O}$ . The  $\text{CH}_4$  and  $\text{H}_2$  contents of the combustion gases can then be calculated from the volume contraction and the volume of  $\text{CO}_2$  produced. The results obtained for cross-sections 10, 11, and 12 are given in Tables 8, 9, and 10.

### Calculation of the Mean Combustion Ratio.

The best method of determining the mean combustion ratio in the pulverised coal flame is that of H. Schwiedessen<sup>17</sup> of which the following is a brief explanation. In  $1 \text{ Nm}^3$  of dry combustion gases  $C_{v1}$  kg. carbon is converted into carbon dioxide,  $C_{v2}$  kg. carbon into carbon monoxide, and  $h_v$  kg. hydrogen into water. Whereas the carbon can be calculated readily from the gas analysis, the only indication of the amount of hydrogen burned is the change in the nitrogen content. The pulverised coal used in the kiln under investigation had only a small proportion of available hydrogen, and the calculation of the amount of hydrogen burned from the dry analysis therefore gives inaccurate results. It is therefore necessary to make certain assumptions regarding the quantity of hydrogen burned.

The heat liberated in  $1 \text{ Nm}^3$  dry combustion gas is

$$H'_e = \frac{k_1 \times C_{v1} + k_2 \times C_{v2} + k_3 \times h_v}{Q_v} \quad \dots \quad (3)$$

On the average,  $1 \text{ Nm}^3$  dry combustion gas contains  $\delta'$  kg. coal having a calorific value of  $H$  Kcal. Therefore

$$H'_m = \delta' \times H \text{ Kcal./Nm}^3 \text{ dry combustion gas} \quad \dots \quad (4)$$

The nitrogen content  $N_2$  of the dry combustion gas can be calculated by the expression

$$Q_v \times p = N_2$$

in which  $p$  is a constant of which the value is to be calculated.

We thus obtain the following expression for the mean combustion ratio

$$\alpha_m = \frac{H'_e}{H'_m} = \frac{P}{N_2 \times \delta' \times H} (k_1 \times C_{v1} + k_2 \times C_{v2} + k_3 \times h_v) \quad \dots \quad (5)$$

### Determination of Calorific Values.

The calorific values of carbon and hydrogen must not be assigned to the calorific values  $k_1$  to  $k_3$  but lower values, which make allowance for the heat of dissociation, must be taken. For coal we can take  $k_1 = 8,080$  Kcal.

As the heat of formation of  $1 \text{ Nm}^3$  carbon monoxide is 0.3 times the heat of formation of  $1 \text{ Nm}^3$  carbon dioxide,  $k_2$  is given by

$$k_2 = 0.3 k_1 \quad \dots \quad (6)$$

As the relationship of  $k_1$  and  $k_3$  to the calorific value determined calorimetrically is

$$k_1 \times c + k_3 \times h = H \quad \dots \quad (7)$$

in which  $c$  and  $h$  are the carbon and hydrogen contents of the fuel used,

$$\frac{k_3 = H - k_1 \times c}{h} \quad \dots \quad (8)$$

### Calculation of the Volume Burned.

From the dry gas analysis we have

$$C_{v1} = 0.536 \text{ CO}_2 \text{ kg. carbon/Nm}^3 \text{ dry combustion gas.}$$

$$C_{v2} = 0.536 \text{ CO kg. carbon/Nm}^3 \text{ dry combustion gas.}$$

$h_p$  can be calculated approximately on the assumption that hydrogen is no longer present in the solid state; according to Schwiedessen this can be assumed with sufficient accuracy when  $\alpha_m > 0.2$ .

$$\text{Then } h_p = \frac{\delta' h_{N_2}}{p} - \frac{2(C_2H_4 + 2CH_4 + H_2)}{22.4} \quad \dots \quad (9)$$

Introducing the calorific values and the quantities burned into the equation for the mean combustion ratio we obtain

$$\alpha_m = 0.536 p k_1 \times \frac{CO_2 + 0.3 CO}{N_2} - \frac{0.0893 p k_3}{\delta' H_u} \times \frac{C_2H_4 + 2CH_4 + H_2}{N_2} + \frac{k_3 h_p}{H_u} \quad (10)$$

### The Numerical Calculations.

With complete combustion and 8 per cent. excess air, 1 kg. of the coal used produces the following volume of exit gas:

C kg. C	produce	$1.86 \times 0.811 = 1.510 \text{ Nm}^3 \text{ CO}_2$
h „ H <sub>2</sub>	„	$11.20 \times 0.043 = 0.482 \text{ „ H}_2\text{O}$
s „ S	„	$0.70 \times 0.010 = 0.007 \text{ „ SO}_2$
n „ N <sub>2</sub>	„	$0.80 \times 0.012 = 0.010 \text{ „ N}_2$
δ „ H <sub>2</sub> O	„	$1.24 \times 0.005 = 0.006 \text{ „ H}_2\text{O}$
N <sub>2</sub> air requirement		$8.22 \times 0.790 = 6.480 \text{ „ N}_2$
N <sub>2</sub> excess air		$= 0.519 \text{ „ N}_2$
O <sub>2</sub> excess air		$= 0.138 \text{ „ O}_2$

Moist combustion gases  $9.152 \text{ Nm}^3$

Therefore the dry combustion gases =  $8.664 \text{ Nm}^3$  and the nitrogen content =  $7.009 \text{ Nm}^3$

The fuel content for  $1 \text{ Nm}^3$  dry combustion gases is

$$\delta' = \frac{1.000}{8.664} = 0.1155 \text{ kg.,}$$

and for the factor  $p$  we have

$$p = \frac{N_2}{Q_v} = \frac{7.009}{8.664} = 0.810;$$

and further, for the calorific value of the hydrogen,

$$k_3 = \frac{H - k_1 \times C}{h} = \frac{7,545 - 8,080}{0.043} = 23,100 \text{ Kcal.}$$

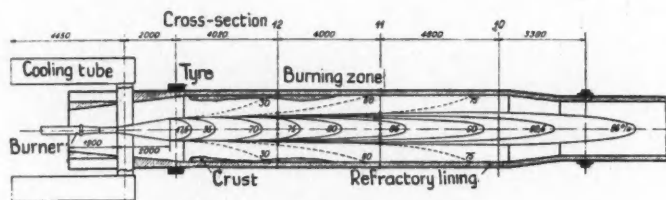


Fig. 17.—Isocalors of the flame in a plane through the kiln axis.

While the values given by the gas analysis can be used as they stand for the calculation of the mean combustion ratio for cross-sections 11 and 12, for cross-section 10 the calculation is complicated by the fact that a proportion of the  $\text{CO}_2$  content is derived from the decarbonation of the raw materials.

Assuming that in this cross-section carbon is no longer present in the solid state it is, however, possible to determine the correct  $\text{CO}_2$  content for the calculation of the mean combustion ratio. Table II gives the values of  $\alpha_m$  for the various points at which samples were taken.

TABLE II.—MEAN COMBUSTION RATIO  $\alpha_m$  AT THE POINTS FROM WHICH THE SAMPLES WERE TAKEN.

No. of Cross-section.	$\alpha_m$ Centre.	$\alpha_m$ 20 cm. from centre.	$\alpha_m$ 40 cm. from centre.	$\alpha_m$ 60 cm. from centre.
10	0.9096		0.9258	
11	0.8321	0.8671	0.9178	0.7533
12	0.7194	0.7383	0.7535	0.6142

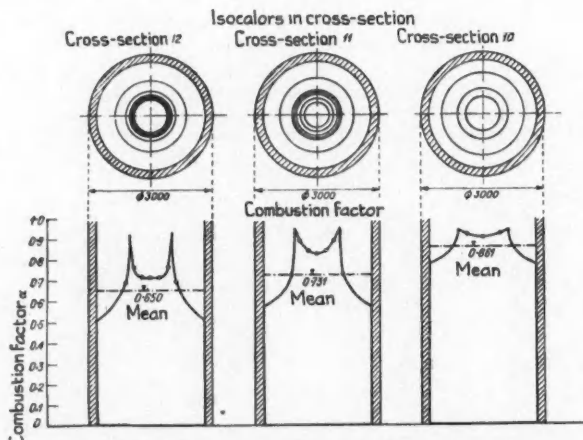


Fig. 18.—Isocalors in the planes of the cross-sections 10, 11 and 12, and the mean combustion factor  $\alpha_m$  at the same cross-sections.

### Isocalorifics.

In any plane section through the kiln the points of equal mean combustion ratio form curves, while within the kiln itself they form areas. The curves, which K. Rummel has termed "Isocalorifics," are shown in *Fig. 17* for a plane through the axis of the pulverised coal flame, and in *Fig. 18*, at cross-sections 10, 11, and 12, for planes normal to the axis of the flame. This representation of the process of combustion gives a clear qualitative picture of the progress of combustion up to the previously mentioned cross-sections and of the state of combustion at these planes.

### Quantitative Determination of the State of Combustion in the Planes of Cross-sections 10, 11 and 12.

To make an exact calculation of the state of combustion in planes 10, 11, and 12 we need the gas velocities and the isotherms as well as the isocalorifics. But as neither of these was determined an approximation was made by multiplying the mean content of unburned material by the mean velocity and the area and dividing the product by  $\delta' \times H$ . In this way the following values were obtained :

$\alpha_m$	= 0.861
cross-section 10	
$\alpha_m$	= 0.731
cross-section 11	
$\alpha_m$	= 0.650
cross-section 12	

### Reaction Volume and Mean Relative Load.

The areas of equal combustion ratio enclose a volume, the reaction volume  $R$ . The characteristic curve shown in *Fig. 19* is obtained by plotting the size of the reaction volume  $R$  against the combustion ratio  $\alpha$ . The curve shows an inflection  $W$  due to the fact that in the first stages the reaction velocity is increased by the rise in temperature. Gradually, however, the influence of the decreasing concentration becomes predominant.

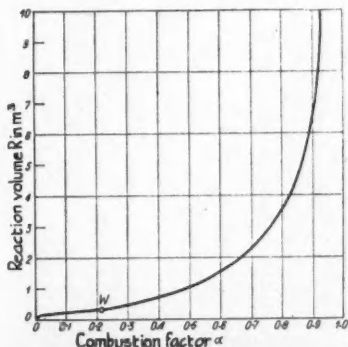


Fig. 19.—Reaction volume  $R$  as a function of the combustion factor  $\alpha$ .

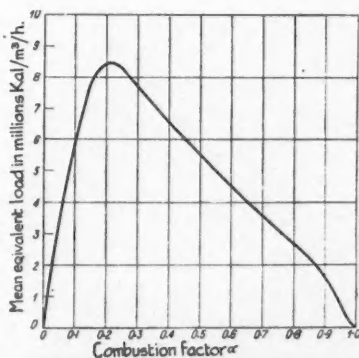


Fig. 20.—Mean equivalent  $b_m$  as a function of the combustion factor  $\alpha$ .

In the volume  $R_1$ , the volume of incipient combustion, the velocity of combustion increases, while in  $R_2$ , the volume of complete combustion, it decreases gradually. The size of the reaction volume finally increases very markedly with the increase in the combustion ratio and the curve approaches the ordinate  $\alpha = 1$  asymptotically.

The mean relative load, i.e. the mean combustion velocity in terms of volume for the reaction volume  $R$  for the combustion ratio  $\alpha$ , is given by

$$b_m = \frac{B \times \alpha}{R} \text{ Kcal/m.}^3\text{h.} \quad \dots \quad \dots \quad \dots \quad (11)$$

in which  $B$  is the load on the furnace in Kcal/h.

The curve in *Fig. 20* shows that complete combustion could only be achieved in an infinite combustion chamber. It also indicates the bad effect of overloading the kiln on the quality of combustion.

(To be continued.)

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### International Congress of Chemistry.

The tenth International Congress of Chemistry is to be held in Rome from May 13 to 21 this year. All branches of chemistry, including building materials, are to be discussed. A programme is now ready, and can be obtained from Via Panisperva 89a, Rome; the London office of the Congress is Ufficio C.I.T., 75-81, Regent Street, S.W.1.

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## Studies on Mixed Portland Cements.\*

By SHOICHIRO NAGAI.

THE latest report of the research on mixed Portland cements now being carried out at the Imperial University of Tokyo, by Professor Nagai, deals with high-silica mixed Portland cements. The following is an abstract of the report.

The paste of neat cement was kneaded with an amount of water to give the normal consistency for determining the time of setting, and moulded in cylindrical test pieces 10 cm. high by 5 cm. diameter. These test pieces were cured in four series, (a) in water for 7 days, (b) in water for 28 days, (c) in water for 7 days and then in warm (50 deg. C.) water for 7 days, and (d) in water 7 days and then in warm (50 deg. C.) water for 28 days. The compressive strengths of these four series of cured specimens were tested, and samples were quickly taken from the fractured surfaces of the crushed pieces and dried in a desiccator. The chemical compositions were determined, and the amounts of free lime or hydrated lime were determined; the results are given in Table 1.

TABLE 1.—Amounts of Free Lime in Hardened Cements.

No. of Sample.	Type of cement.	Amount of free lime.			
		Room temperature water curing for		Room temperature water and then warm water curing for	
		Week 1	Weeks 4	Weeks 1+1	Weeks 1+4
No. 486	Common Portland cement	10.5 %	11.2 %	12.4 %	13.5 %
" 489	" " " "	10.6 "	11.9 "	12.8 "	13.7 "
" 490	Moderate heat P.C. " "	7.2 "	10.4 "	10.8 "	12.9 "
" 491	Blastfurnace slag cement	6.6 "	5.4 "	4.4 "	3.5 "
" 492	High-silica mixed P.C. " "	10.2 "	11.8 "	7.2 "	6.3 "
" 493	" " " "	10.5 "	9.8 "	8.2 "	5.6 "
" 494	" " " "	9.1 "	9.7 "	6.6 "	6.1 "

From these results it is seen that the amount of free calcium hydroxide increases in Portland cement but decreases in mixed Portland cement. This shows that the high-siliceous admixture used in mixed Portland cement combines with calcium hydroxide set free by hydration.

The strengths of dry (or non-plastic) and wet (or plastic) mortars of these cements were tested at longer curing ages (3, 6 and 12 months) than the standard curing ages (3, 7 and 28 days). The increase in strength is greater in high-silica mixed Portland cements than in common Portland cements due to the combination of siliceous admixture and calcium hydroxide produced in set cement.

The expansion and contraction of mortars were tested by prismatic (4 cm. by 4 cm. by 16 cm.) test pieces moulded with wet mortars and cured in water for 3, 7, 28, 91, 182, and 364 days. The results show that the contraction or expansion

\* Previous accounts of this research work were given in our issues for February, 1936, and June and September, 1937.

was less in the case of high-silica mixed Portland cement than in the case of common Portland cement; contrary results are obtained with air curing.

The corrosion, expansion or contraction and variation of strength by curing in water, 10 per cent. NaCl solution, and 10 per cent.  $\text{Na}_2\text{SO}_4$  solution were studied by using prismatic test pieces of wet mortar immersed in water or salt solutions for 4, 8, 12, 16, 20 and 24 weeks. Expansion cracks and then disintegration were seen in the test pieces in 10 per cent.  $\text{Na}_2\text{SO}_4$  solution, especially in common Portland cement and blastfurnace slag cement. This is due to the large amount of alumina in the cement, and the formation of  $x\text{CaO} \cdot y\text{Al}_2\text{O}_3 \cdot z\text{CaSO}_4 \cdot n\text{H}_2\text{O}$  (so called cement bacillus). These results were clearly seen in the disintegrated test pieces, and coincide quite well with those recently reported by G. Haegermann (*Zement*, 1937, 26, 210).

The decrease in strength was most marked in the specimens cured in 10 per cent.  $\text{Na}_2\text{SO}_4$  solution, followed by those cured in water and 10 per cent. NaCl solution. The decrease in strength was also most marked in the specimens of common Portland cement, followed by blastfurnace slag cement. The high-silica mixed Portland cement gave the best results in all cases. This is the most important advantage of high-silica mixed Portland cement.

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DUST COLLECTION.—A useful catalogue illustrating and describing "Davidson" patent centrifugal flue-dust collectors, of which more than 1,500 are now in use, has been issued by the manufacturers, Messrs. Davidson & Co., Ltd., of Belfast. The catalogue gives a great deal of information on grit emission and flue-dust analysis, and is a valuable addition to the literature on the subject. These collectors are in use in cement works, and copies of the catalogue will be sent free to cement manufacturers and others interested in the problem of dust emission.